Visual artifacts as decision analysis and support tools

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Abstract

Humans make a myriad of decisions every day. Some can be made without any conscious cognitive effort, while others require intensive and iterative reasoning and calculation. This paper examines the cognitive processes responsible for decision making through a review of relevant research from the fields of cognitive science, human factors, and decision science. Additional focus will be placed on visual displays and their role in the decision making process.

Background

Decision-making is generally described as a task in which one has to choose a path of action from a set of available options during a certain period of time (Wickens et al., 2004). Some information is generally provided regarding the available options, but this can range from vague descriptions to quantifiable metrics (Wickens et al., 2004, Slovic et al, 1988). As such, most decisions involve uncertainty and require consideration of multiple theoretical outcomes before settling on a course of action (Slovic et al, 1988).

Traditionally, the study of decision making has been rooted in the fields of economics, mathematics, and philosophy (Slovic et al, 1988). Early attempts at creating psychological models for decision making, such as Edwards (1954), borrowed several concepts from the traditional studies of decision making. Of particular importance in the traditional studies was the notion of "utility", or overall value associated with any potential decision path. The traditional view, often referred to as the normative model, posits that decision making is essentially a matter of maximizing utility: selecting the option that provides the greatest overall value to the task at hand. The normative model assumes several key characteristics about the decision maker (Slovic et al, 1988):

1. The decision maker is aware of every available option and all of its associated consequences.
2. The decision maker is capable of distinguishing between the details of every available option.
3. The decision maker will behave in a manner that follows utility maximization rationality.

The nature of the human information processing system, and the limits of the working memory system in particular, lie in direct opposition to these assumptions (Baddelley, 1986; Boff et al., 1986). As such, cognitive scientists attempted to develop models that describe decision making within the context of the mind's cognitive strengths and weaknesses (Slovic et al., 1988).

The Descriptive Decision Making Model

Cognizant of the mind's information processing limitations, Simon (1956) proposed that rather than seeking absolute utility maximization, the mind tends to accept a simplified mental model of the decision making task and merely attempts to find a "satisficing" (i.e., satisfying and sufficient) solution. In many cases satisficing produces acceptable and even preferable results; such simplified schemas, or heuristics, can lead to more efficient decision making by eliminating the consideration of low-relevance variables (Gigerenzer & Todd, 1999). In some cases however, such simplification can produce mentally satisfactory solutions that stray drastically from the normative model and potentially lead to error (Wickens et al., 2004). Understanding the reasons for such limitations or biases requires a more detailed examination of the decision making process.

Wickens (1992) presents a three-part decision making process that consists of 1) the acquisition of perceptual cues, 2) development of diagnostic and descriptive hypotheses based on cue combinations, and 3) selection and execution of action. As perceptual stimuli are obtained, they are transferred to the working memory for analysis (Boff et al., 1986). In some situations, an abundance of perceptual cues may overburden the working memory system and lead to the negligence of certain cues (Boff et al., 1986). Additionally, the information processing system is susceptible to inherent biases that place disproportionate emphasis on certain types of cues (Wickens et al., 2004). Research by Adelman et al. (1996) for example, has shown that cues received early in the decision making process tend to be more prominent in the working memory and receive greater attention in the hypothesis generation stage. Similarly, Endsley (1995) notes that the strength of a perceptual signal also affects its perceived relevance to the decision making task. Such biases, while a natural part of the information processing system, are rather counterproductive, as a cue's order or strength doesn't necessarily correspond to its relevance.

Ignoring or misjudging cues is potentially dangerous because it can lead to faulty hypothesis and/or plan generation (Wickens et al., 2004). Even with proper consideration of all available cues, hypotheses and plans are susceptible to biases. The limits of working memory generally allow the development of one to four hypotheses, only one of which is likely to receive a thorough analysis (Mehle, 1982). Given the multiple variables, causes, and effects associated with any hypothesis (i.e., heavy working memory load), the mind tends to fixate on a single, and early developed option; a bias often referred to as cognitive tunneling (Cook & Woods, 1994). As research by

Rubinstein and Mason (1979) has shown, cognitive tunneling can cause people to maintain early plans in spite of contradictory evidence. Because hypotheses and plans are drawn from long term memory, domain experts are more likely to develop fruitful hypotheses in spite of cognitive tunneling, but are still susceptible to other biases. Research by Anderson (1990) suggests that recent or frequently considered pieces of information also tend to have a strong influence on hypothesis generation.

Some decision related biases are a result not only of processing limits, but also of the manner in which the decision can be presented. Kahneman and Tversky's (1984) seminal research suggests that the decision making problems can be "framed" in different manners, each option affecting the decision makers process in finding the optimal decision.

While many decision making tasks can tolerate the effect of humans' natural biases, some are too complicated, critical, and/or risky to rely on the mental effort alone. Zhang (2001) notes that in such situations there is tremendous benefit to externalizing the cognitive task through the use of visual artifacts.

Visualization and Decision Making

According to Slovic (1972, p.14), "…a judge or decision maker tends to use only the information that is explicitly displayed in the stimulus object and will use it only in the form in which it is displayed." When present in the context of a decision environment, displays of related information, and their visual structure, have a noticeable effect on the decision making process; research by Russo (1977) for example, has shown that consumers are only likely to consider unit price information when it is presented in a simple organized list. As such, the visualization of decision-related information provides great opportunity for assisting the human information processing system and potentially even countering some of its innate biases. What follows is a review of several visualization techniques and their associated strengths and weaknesses.

Multi-attribute tables

Even in the absence of risk and uncertainty, certain types of decisions offer a potentially overwhelming number of options. Such decisions are often well represented by multi-attribute tables or matrices that display the available options, their interrelated characteristics, and the resulting expected utilities (Harris, 1999). Though primarily a number and text based presentation format, multi-attribute tables embody certain visual strengths that are occasionally preferable to purely textual or linear presentations. First, they allow a large amount of data to be presented in a small area and thus be perceived simultaneously. Second, the table's grid allows for pre-attentive groupings to emerge. Together these two factors allow one to easily (i.e., with relatively little burden on working memory) make comparisons and perceive relationships between separate choices, attributes, and expected utilities. Arguably, the use of numbers presents a potential area for further leveraging of cognitive load, as they could be replaced by perceptual symbols that communicate quantity through size. There is however conflicting research regarding the optimal method, as graphical and iconic representations have shown to be preferable in some decision making situations (Elting et al., 1999) whereas tabular presentations of numerical information have shown to be preferable in others (Vessey, 1991).

Probability Modeling Diagrams

Zhang (2001) notes that while a great benefit of visualizations is their ability to support memory, some visualizations are "…intrinsic components, without which the tasks either cease to exist or completely change in nature" (p. 3). Research by Edwards (1968) has shown that in combining probabilistic information for decision making, humans have a tendency to develop estimates that are more conservative than those suggested by mathematical models (such as Bayes' theorem). Diagrams and interactive displays such as Bayesian Boxes (see Figure 1) visualize the relationship between prior and conditional probabilities in order to move peoples' naturalistic estimations closer to the normative Bayes model. By showing potentially tough to calculate quantitative data as size-based representations, such diagrams allow the probability calculation to be executed by the eyes alone. According to Burns (2004), such diagrams are beneficial because they display the quantitative results but also visualize the underlying logic in ways that have been shown to improve peoples' long term understanding of Bayesian reasoning (Gigerenzer & Hoffrage, 1995).

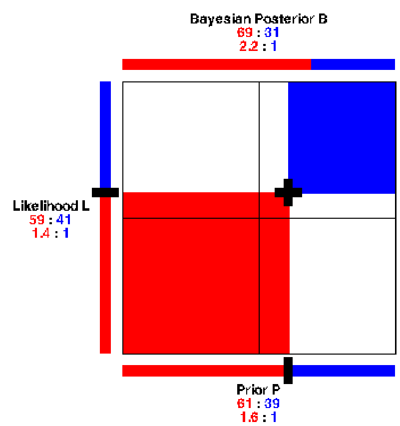

Figure 1 - A sample Bayesian Box diagram

Decision Trees

A common display type used for decision analysis and support is the decision tree, a node-link diagram which represents potential options and their associated consequences (see Figure 2). Additionally, decision tress can include probabilities, quantitative outcomes, and contextual information within and around nodes and links (Harris, 1999). Decision trees' perceptual strength lies in the node-link structure, which utilizes humans' pre-attentive strengths to present rather complex cause and effect chains that can be reviewed and analyzed with relative ease (Ware, 2000). Visually reviewing cause and effect of decisions frees up working memory which can then be utilized to analyze and critique the different options with greater consideration and decrease the chances of accepting faulty hypotheses. The act of constructing the decision tree is itself beneficial to the decision making process. Similar to mind maps and their ability to provoke prolific divergent thinking, drawing decision trees allows one to externalize the thought process and potentially develop more hypotheses than would be possible in the mind alone, thus increasing the chances of encountering choices that produce greater utility. Such processes however, require amounts of time that may not be available in some cases such as medical emergencies. Thus, computer-generated decision diagrams can also be presented as part of a decision support system.

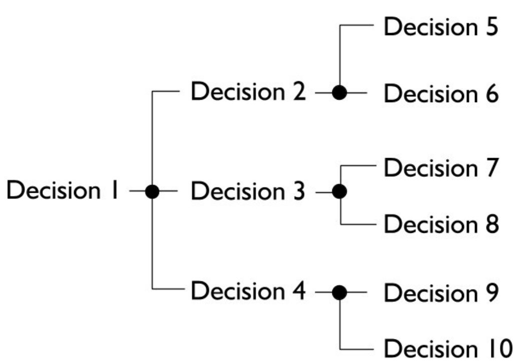

Figure 2 - A basic decision tree

Case Study

One of the most prominent areas of study in decision making is the medical field. Clinical professionals make complicated and critical decisions, often under severe time constraints, on a regular basis. The enclosed visualization (see Figure 3) is a hypothetical attempt at combining some of the enabling features of the aforementioned display types in effort to address some of the needs of such complicated decisions. The diagram's structure is based on decision trees, showing the cause and effect of different treatment options. Rather than being presented numerically, probabilistic and quantitative information is visually coded into the diagram to facilitate its perceptual integration. The lines that connect the different options represent the combined probabilities for each option, with line thickness representing a choice's conditional probability (thicker lines representing higher probabilities) and line brightness representing base-rate information (darker tones representing higher probabilities). Such coding decreases the need for mental probability calculations by making the more probabilistic options more conspicuous.

The nodes in the enclosed diagram have also been expanded to include additional attribute information that may be relevant to the decision making process, similar to expanded decision diagrams discussed by Coury et al, (1997). In clinical decision making, various interrelated attributes and variables, such as heart rate or blood pressure, act as critical cues. Presenting such attributes as horizontal bars embedded in the nodes allows the viewer to visually perceive quantitative differences between the different choices and make quick comparisons of the different options. Additionally, calculated color coding can be used to attract the viewer's attention towards the most critical cues; for example utilizing strong colors such as saturated yellow to code dangerously low or high attribute levels. In this regard, the salient qualities of the display can be used to counter biases that cause people to over-consider prominent environmental cues.

Admittedly, some of the perceptual techniques used in the sample diagram also have the potential to create negative results. The visually salient qualities of certain cues and choices can themselves bias the viewer, potentially causing him/her to accept the visual presentation and neglect additional analysis (i.e., deskilling). Further refinement of the design and additional research would be required to determine the overall utility of such visual attributes.

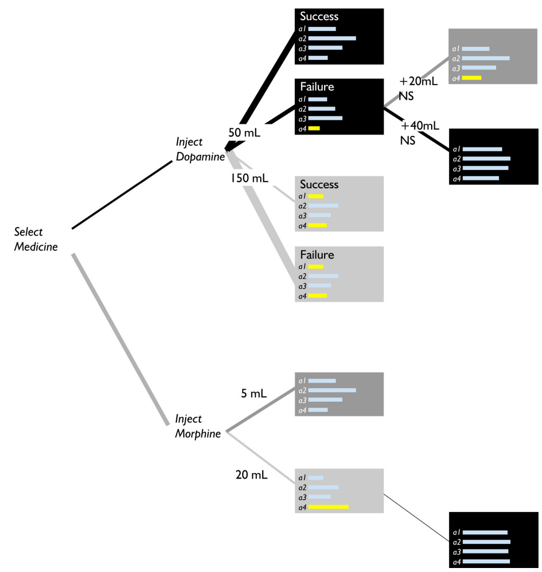

Figure 3 - Experimental diagram design

Conclusion

Decision making remains a fertile and highly relevant area of study. New methods, such as functional magnetic resonance imaging, are confirming previous descriptive models and exploring new areas of decision making. Simultaneously, advances in artificial intelligence are allowing the development of complicated decision support systems that are used in a variety of fields. Ideally, designers of such systems and displays should be considerate of the cognitively-based decision making research and permit the development of systems that enhance decision making without making it a mindless activity.

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